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Prospect of IoT Based Control System for Enhancing Wind Turbine Capacity in Bangladesh

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Abstract

With the advancement of science and technology in the last few decades, the increasing demand of electricity is ineluctable. This phenomenon is further being alarming as energy resources are depleting at a high rate. The efficient renewable energy harvesting technologies should be the solution to face this difficulty. Harvesting wind energy can serve as a sustainable method for electricity generation. But existing wind turbines have poor coefficient of performance due to turbine alignment degradation during their operation. This problem can be mitigated by using internet of things (IoT) based wind energy extraction system. This paper proposed the IoT technology in wind turbine, in which an individual air flow detection system is built; and this system is connected with the turbine through cloud. Inherently, this technique could provide a turbine which is free from air flow detection attachment in the hub of the turbine as well as efficient wind energy capturing.

Keywords: Wind turbine, IoT, renewable energy.

1. Introduction

Renewable and clean energy resources have become a demanded research area due to the increasing energy demand and fast depletion of natural resources. The world electricity demand will increase by almost 80% during the period of 2012-2040 in the (IEA) International Energy Agency's New Policies Scenario [1]. Renewable energy harvesting can be a felicitous alternative for existing energy generation methods that depend on natural resources for electricity generation. The energy demand is increasing significantly in Bangladesh as well. A sustainable long-term power development plan has been prepared for mitigating the growing demand to reach the generation capacity 24000 MW by 2021 [2]. Revised generation expansion plan updated in August 2018 targeting about 15,000 MW generation additions from 2018 to 2021 is shown in a graph below [2].

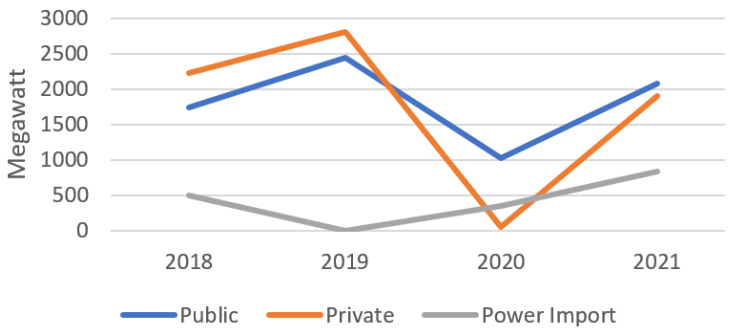


Fig. 1. Year wise generation projects to be completed (From 2018 to 2021)

Wind energy is one of the fastest growing renewable energy sources in the world. Utilizing wind speed can be an economically viable method for electricity generation in Bangladesh. The wind speed in the coastal areas can be utilized for electricity generation. Bangladesh has 740 km long (straight line) coastal belt facing the Bay of Bengal. A simple calculation showed that, if 5% of the coastal areas (up to 10 km to the inland) are used to install the 2.5 MW size wind turbines, the total gross potentials of wind power will be more than 25000 MW [3].

Technical analysis shows that wind home system for coastal islands is quite better than solar home system [4]. Studies carried out by various researches show that the coastal belt and islands are suitable for wind generators

and fairly potential for small scale wind energy system [4], [5]. Horizontal axis wind turbines are the most popular wind turbines used throughout the world. They have to be aligned with the main wind direction to maximize the energy yield. Attempts have been made to improve the yaw alignment with advanced measurement equipment but most of these techniques introduce additional costs and rely on alignment tolerances with the rotor axis [6]. Internet of Things (IoT) based wind extraction system can be the solution to face this difficulty.

But even turbines that can align perfectly with the main wind direction at the beginning of their service, face alignment degradation during their operational lifetime. Internet of Things (IoT) based control system can be used to control the alignment with the main wind direction. This will ensure that alignment degradation is detected as soon as possible to minimize power loss. IoT can also be used to determine any fault in the existing wind turbines. It registers the consequence of the fault, and responds referring to the type of the malfunction. In order to avoid safety hazards or main system breakdowns, the turbine has to be shut down [7]. In addition to this, the site manager will be able to receive detailed information of facility at site. The maintenance process will be more efficient, reliable and cost efficient. Controlling and monitoring even from a remote distance is possible in order to achieve smart recognition, tracing, positioning and administration. This paper discusses about the prospect of IoT based control system for wind turbine for efficient wind energy capturing, visioning the future potential of this technology.

2. IoT based wind energy extraction system for wind turbine

The IOT concept was first introduced by a member of the Radio Frequency Identification (RFID) development community in 1999, and it has recently become more relevant to the practical world largely because of the growth of mobile devices, embedded and ubiquitous communication, cloud computing and data analytics [8]. IoT based wind energy extraction system will perform suitably for 50-300 kW plant at almost the same setup. So, the turbine capacity can be enhanced without increasing the investment in the same rate.

Individual air flow detection setup

In the IoT based wind energy extraction system, the air flow detection system is an individual setup, which is connected with a turbine through cloud. This will provide a turbine which is free from air flow detection attachment in the hub of the turbine. So, the need to attach bulky wind detection device with the turbine will be eliminated. Arbitrary control of wind turbine is also possible by implementing this system. As IoT system can create interconnection between different devices, it has the inherent ability to control multiple wind turbines as well. In this case, an individual structure can be used to control the turbines at once which is shown in Fig. 2.

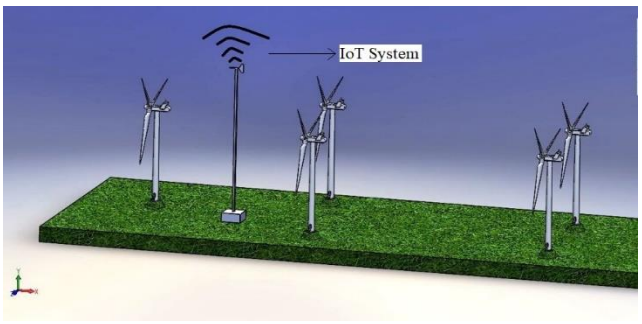


Fig. 2. IoT system to control multiple wind turbines at once

Main components needed for the system

In order to install IoT based control system for wind turbine an individual structure should be installed on the wind farm. It will have a wind vane to detect the wind direction, potentiometer, ESP 8266 module and a Wi-Fi router.

ESP8266 module is used to transmit and receive the electrical data wirelessly. The ESP8266 transmitter can be interfaced with sensors and reliable data reception at a receiver side of ESP8266 module. This enables user to have flexible control mechanism remotely through a secured internet connection. ESP8266 Wi-Fi module can be used to connect to the internet and it is linked to the website through which we can operate from anywhere in the world [9], [10]. The potentiometer is connected with the wind vane. When the wind direction changes, the wind vane will move accordingly. This will cause the potentiometer to rotate too; consequently, a change in resistance will be generated by the potentiometer. Arduino will analyze the data sent from the potentiometer and rotate the servo motor accordingly. Wi-Fi router is used for better data transmission and reception. The main components used for the IoT based system can thus be categorized into two sections, namely sensing section and actuating

section. The sensing section will detect the wind direction and the actuating section will rotate the turbine for proper alignment with the wind direction. The main components used for the system is shown in figure 3.

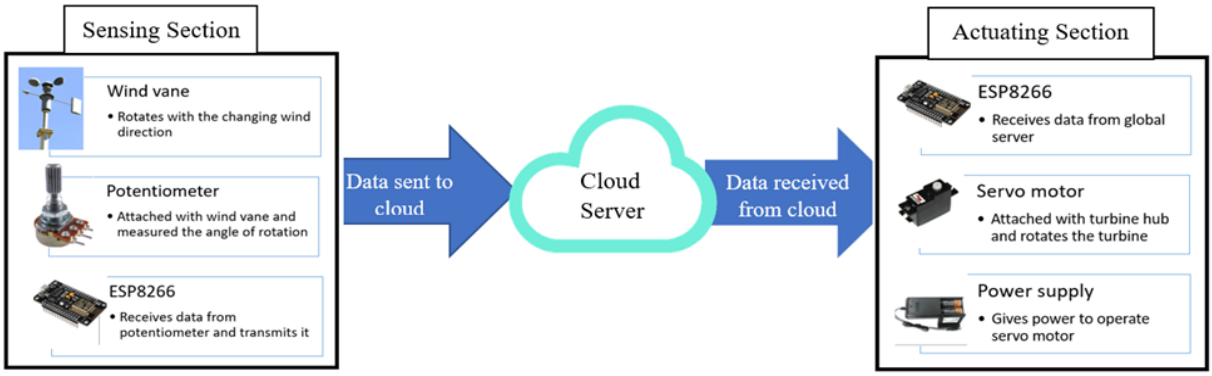


Fig. 3. Components used for the IoT based system

Layout

The proposed layout for the system is shown in figure 4.

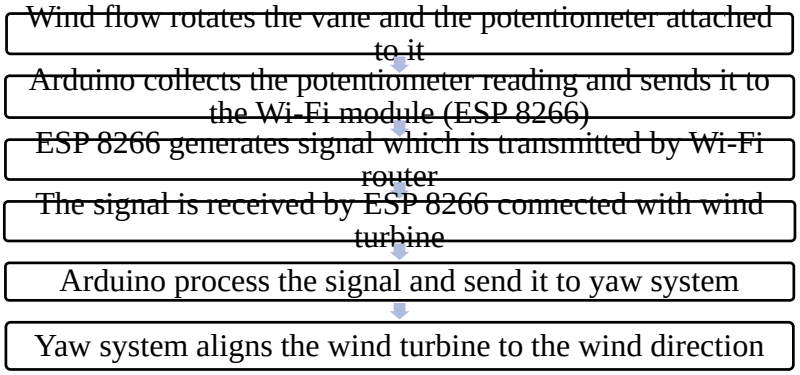


Fig. 4. Layout for wind turbine alignment with the main wind direction

4. Extractable Wind Energy

Wind turbines harness the kinetic energy from the wind and convert it into electrical energy. However, total kinetic energy can't be utilized. The theoretical formula for utilized wind energy is given below.

Theoretical wind energy = (Air Density × Area covered by a turbine blade × Velocity^3)/2 Watt-hour (1)

However, in real life, a coefficient of performance (C_P) is included in the equation as the turbine can't harness all the kinetic energy from wind. According to Betz Limit or Betz' Law the theoretical maximum coefficient of performance for any wind turbine is 0.59. That is, not more than 59 per cent of the energy carried by the wind can be extracted by a wind turbine [11]. In real world, Betz Limit with values of 0.35-0.45 is common wind turbine. It varies with wind speed, turbulence and operating characteristic [12].

Ideal wind energy = (Air Density × Area covered by a turbine blade ×Velocity^3×C_P)/2 Watt-hour (2)

Where the area covered by a turbine blade = $\pi \times R^2$ (where, R is the radius of a turbine blade), C_P = Coefficient of Performance, Air density = 1.2 kg/m^3 and the coefficient of performance (without IoT system) = 0.38 (Considering generator and transmission loss)

Choosing the area

In order to find out the enhanced extractable energy by using IoT system, at first the wind speed at various regions in Bangladesh is needed to be find out. The average wind speed at the 25-meter height at various regions in Bangladesh were collected from various research papers [4], [5], [13], [14] and shown in Fig.2.

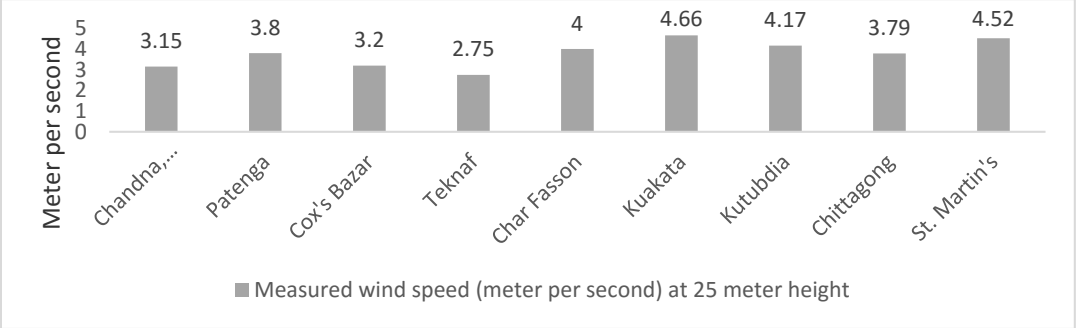


Fig. 2. Average wind speed at the 25-meter height at various regions in Bangladesh

As wind energy depends on the cube of wind speed, (V^3), it is therefore feasible to set up wind turbines at regions where the wind speed is relatively high. Therefore, instead of setting up wind turbines throughout Bangladesh it will be more feasible to install wind turbines at the coastal areas due to the high wind speed.

Southern and Eastern sides of Kutubdia appear to be promising for wind electricity generation using large turbines where wind power density at a height of 50 m or higher is found to be above 200W/m^2. It is found that at 30 m height, the coast side of Kutubdia should be sustainable for small turbines [5]. Hussain et al. surveyed wind speed in coastal locations using handheld anemometers and stated that Chittagong seacoast and coastal islands have a fairly high wind speed and may serve as a good location for setting up wind turbine [15], [16]. It won't be feasible to set up wind turbine in Chandna, Teknaf and Cox's Bazar due to availability of low wind speed. In this case, low cost wind turbine can be considered that work better at low wind speed.

Case I: Using the prevalent wind turbine specifications (50 kW rated capacity) in Bangladesh

Case I is focused on the existing wind turbine technology implemented in Bangladesh. The hub height is considered to be 25 meters, while the radius of a turbine blade is 7.5 meters. Thus, Area = $\pi \times R^2$ = 176.71 m^2 (for turbine blade radius, R =7.5 meters). Using Equation (1-3) the enhanced extractable energy by implementing IoT in several regions in Bangladesh is shown in Table I.

Table 1. Extractable wind Energy in Watt-hour at different regions in Bangladesh

Region	Wind Speed at 25-meter height	Extractable energy in Watt-hour (No misalignment considered)
Chandana, Gazipur	3.15	126.91
Patenga	3.8	153.10
Cox's Bazar	3.2	128.93
Teknaf	2.75	110.79
Char Fassion	4	161.16
Kuakata	4.66	187.75
Kutubdia	4.17	168
Chittagong	3.79	152.69
St. Martin	4.52	182.11
Average	**3.78**	**152.38**

Without any misalignment issues the 50-kW rated capacity turbine is expected to yield around 150 Watt-hour energy. However existing wind turbines will generate less energy due to turbine alignment degradation during their operation.

Case II: Considering turbine of 300 kW rated capacity

Case II is a prognostication about how IoT system would increase the extractable wind energy when used with comparatively better wind turbine. Representative height and diameter of wind turbines [17] are shown in Fig. 4.

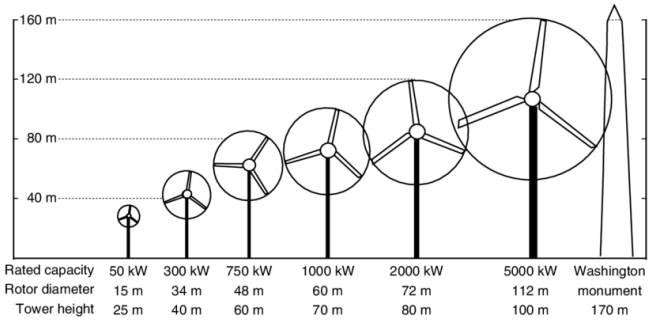


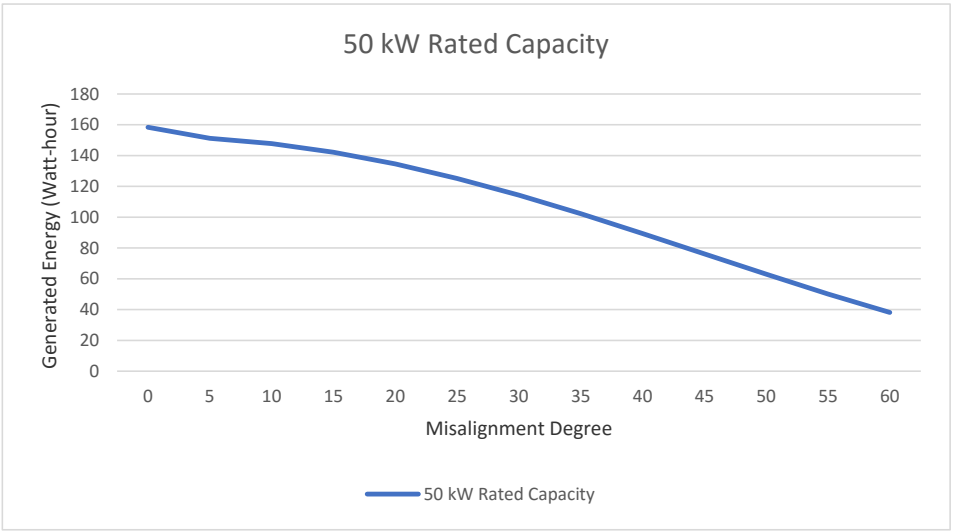
Fig. 4. Representative size, height and diameter of wind turbines [17]

Here the turbine height is considered to be 40 meters, while the diameter of a turbine blade is 34 meters. Thus, Area = $\pi \times R^2 = 907.92\ m^2$ (for turbine blade radius, R =17 meters). In Bangladesh, on average wind speed varies from 4m/s to 5.5 m/s at the height between 25m to 50m [3]. The wind velocity at 40-meter height is taken to be 4 m/s.

Extractable energy by implementing IoT (for one wind turbine) = $(1.2 \times 907.9 \times 4^3 \times 0.38)/2$ Watt-hour = 13248.0768 watt-hour = 13.24 kW-h

Misalignment issues considered

When the misalignment issues are considered the energy output will be reduced. The higher the misalignment angle the greater will be the loss in generated energy.



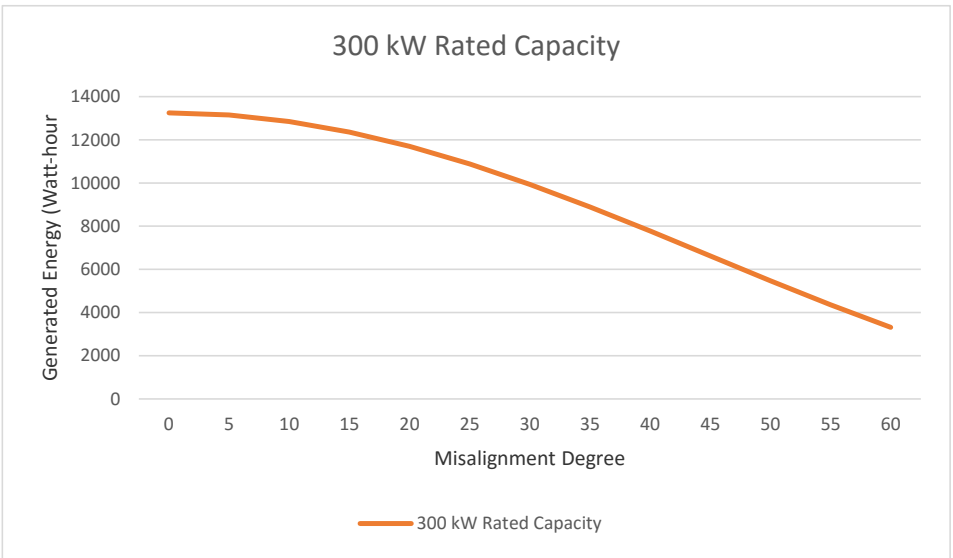


Fig. 5. Loss in generated energy due to misalignment angle for 50 and 300 kW rated capacity turbines

6. Conclusion

This paper provided a study of insight to the prospect of using IoT based wind turbine. IoT based wind turbine will have a profound impact in incoming days to meet the efficient and fluctuated energy demand. Using IoT for wind turbine was found out economically viable and extraction of wind energy could be increased significantly without increasing the investment in the same rate. Payback period will significantly reduce for high capacity turbine as almost same capacity of IoT based setup can perform suitably for 50-300 kW plant. For better utilization of wind energy, IoT based wind turbine is surely the way to be forwarded.

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